HARVESTING OF ALGAE BY INDUCED FLOCCULATION

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By
B. P. SAHANI "ARUN"

to the

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JULY 1973

CERTIFICATE

13.7.73

This is to certify that the present work entitled "Harvesting of Algae by Induced Flocculation" has been carried out by Sri B.P. Sahani "Arun" under my supervision and the work has not been submitted elsewhere for a degree.

A.V.S. Prabhakara Rao
12/7/73

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B. P. SAHANI

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This study describes separation of algae from stabilisation pond effluent through induced flocculation, without the use of any chemical. With the help of domestic blender and a fractional horse power recirculation pump it was possible to induce bioflocculation of algae. The relationship between percent removal of algae and energy consumption per unit volume of the algal suspension was exponential in nature in both the cases. The efficiency of removal was higher with the blender than with the pump. Removal upto 90% was recorded with the former. It was also observed that the efficiency increased with the increase in rate of energy consumption. Low-speed mixing was found to be practically ineffective in this process.

The harvested cells did not grow in a synthetic medium indicating that they are most probably non-viable. From certain studies it was inferred that the mechanism of removal of algae was due to some sort of exo-cellular polymer that separated out from the cells during the operation.

CHAPTER I

INTRODUCTION

1.1 GENERAL OUTLINE

With rapid growth in the world population even seemingly limitless natural resources like food, fuel and water are getting scarce. Growing number of industries and ever increasing affluence in the society are further multiplying the world problems by polluting the environment. The very civilisation looks threatened by pollution and is confronted with mammoth challenge to provide clean air, safewater and adequate quantity of nutritious diet to the present and future generations. Conditions are comparatively better in some of the western countries but the problems are far more acute in developing countries like ours; for instance, more than 90 percent of the population has no option than to drink unsafe water (42). The major portion of the urban population is obliged to live in slums and ghettoes. The environment in such areas has a very degrading effect on the quality of human life. Particularly disastrous effect is on the growing children who suffer both mentally and physically.

Our milch animals such as cows and buffalo produce muchless quantity of milk per lactation as compared to those in western countries, mainly because of inadequate quantity and substandard quality of fodder, they are fedwith; extremely poor quality of water, they are served with; and intolerably unsanitary conditions, they are kept in.

It is no doubt a big problem and it is extremely difficult to solve it in short time mainly because of large population and vast area of the country. Even for providing basic minimum requirements of nutritious diet and safe water to all the people it would entail too huge an expenditure to afford at present at least, if not in future. The problems can reasonably be cut down to a workable size if we, at least stop polluting our natural water resources and adopt an unconventional means of food production. A reasonably good solution might be at hand if treatment of domestic and industrial wastes is accomplished to a desirable extent before discharging them to natural bodies of water and the byproducts of the above treatment processes could be utilised for various other beneficial uses.

Treatment through stabilisation ponds is a good solution to meet both the objectives at a time. This method, along with economic treatment of sewage, produces a highly nutritive byproduct i.e. algae,which have the potential to be utilised for various beneficial purposes. Other advantage of this method is that it has been found to be the cheapest amongst all the conventional methods of sewage treatment within a population-range of 5000 to 2,00,000 people provided the cost of the land does not exceed Rs. 55,000 per acre (1). The method is easily adoptable in India since most of Indian towns fall within the above mentioned population range, with plenty of cheaply available land and favourable climatic conditions alround the year.

1.2 SIGNIFICANCE OF ALGAE IN STABILISATION POND

Treatment of wastes in stabilisation ponds is mainly achieved through photosynthesis. In these ponds bacteria decompose organic constituents of the wastes and nutritional products of decomposition are made available to algae. The algae by trapping solar energy and utilising the nutrients made available by bacteria give rise to more algal cells, as well as produce oxygen which in turn is used by bacteria to oxidise the wastes.

The current practice of disposal of effluent from stabilisation ponds is either by seepage or through stream disposal or unscientific land irrigation. Disposal through stream is quite common in practive. This type of disposal causes taste and odour problems clogging of filters, etc. In addition, when algae decompose they increase BOD load in the streams and pose danger for fish and other aquatic life (2). Algae as such are a useful product and their wastage in the effluent is not only a loss but has contributory effect towards increasing the eutrophication and the natural biological problems associated with fresh water environment.

As reported in literature (3,4) algae generally contain ten aminoacids & large amount of vitamins A,B,C. The algal cells contain on an average 50 to 60 percent protein, 20 to 30 percent lipids, and 10 to 20 percent carbohydrates (5). Because of likely presence of pathogens, sewage grown algae might not be suitable for direct human consumption but they can be used as chicken-and live stock feed (6). They can also be used as fertilizer (7) or as fuel, either directly by burning or indirectly by producing methane through anaerobic digestion (8). It

is reported in text book (9); that the net fuel value of methane is 963 BTU/Ft^3.

As mentioned earlier, algae; that grow in stabilisation ponds are highly useful product but are liable to create further problems if, not removed from pond-effluent before discharging it to streams or otherwise. Besides this, stabilisation pond-algae utilise the wastes which are obnoxious, disposable and cheapest type of nutrients and in return they give a highly nutritious algal yield in stabilisation ponds which is a high yielding crop. As per CPHERI report (10) algal yield as high as 12 tons/acre-year in winter to 60 tons/acre-year in summer has been recorded. Studies by Oswald *et al*. (4) further indicates that the nutritional value of algae is not much altered by their method of mass culturing.

Harvesting of algae becomes difficult economically because of their low concentrations, microscopic size, and low specific gravity. Number of methods such as centrifugation, chemical precipitation, filtration, ion exchange, sedimentation etc. have been tried by many workers including Golueke, Oswald and Gee (11). They report that, none, except chemical precipitation would be practically feasible. They further report that

centrifugation would have been a possible means of harvesting but becomes highly uneconomical because of high initial and operating cost. Algae harvested by chemical precipitation contains an appreciable percentage of chemicals used in the process of harvesting. Presence of such chemicals restrict the further use of the harvested algae, e.g., algae harvested by this method could not be digested anaerobically in an experimental study made by Saini (8). Methods used by Ramchandran (12) and Kumara Sastry (13) for harvesting algae involve the use of a costly (Rs. 1200/Kg.) and scarcely available cationic surfactant, Hexa-deca pyridinium chloride ($C_{21}H_{38}$ Ncl) which is not manufactured in India. In addition, this chemical escaping along with concentrated algal sludge might affect its nutritional quality and preclude the use of algae for other beneficial purposes.

1.3 OBJECTIVE OF THE PRESENT STUDY

The present study has been undertaken to find out a feasible method of harvesting algae from stabilisation pond-effluent without using any chemical. Since it is not intended to use any chemical in the process of harvesting it is expected that the algae harvested by this method would be qualitatively much better than that harvested by chemical precipitation or froth flotation.

CHAPTER II

LITERATURE REVIEW

2.1 HISTORY OF STABILISATION POND

Existence of stabilisation ponds in one form or other antidates the prehistoric times and they are no more a novelty now. From time to time they have been referred to by many names such as oxidation ponds, redox ponds, maturation ponds, sewage lagoons, anaerobic lagoons facultative lagoons, etc. (5). Use of ponds, depressions and lagoons or any other natural or designed retaining basins to treat wastes is not new (14). It is believed that moats that surrounded the castles of the middle ages, functioned not only as defensive devices, but also incidently served the purpose of stabilisation ponds where algae flourished and played the vital role of purifying sewage that resulted from the community living within these castles and invariably entered this body of water (15). But the purification potential of these ponds was realised much later. It was Gillespie (16) who gave the first published description of the ponds of Santa Rosa, California, U.S.A., which were built in 1924.

Review of many papers on stabilisation ponds have been published by Fitzerald and Rohlich (14).

The use of stabilisation ponds in India is virtually unrecorded historically. But in recent years ponds have however come to be installed as distinct treatment devices, designed on the basis of certain empirical or rational criteria. Perhaps the first small installation was a pond for the Madras University-Campus built in 1957. The first large scale installation was the one, at Bhilai where it serves a population of about 100,000 people. These ponds are receiving increasing attention at present and there are now over 50 ponds in operation in India (5).

Ponds for treatment of industrial wastes combined with domestic sewage have been constructed, for example, in Bombay by a pharmaceutical firm; near Kanpur for a sugar factory; in Hyderabad for milk wastes; and ponds are also under construction for treatment of wastes from a fertilizer factory (5).

2.2 MECHANISM OF PURIFICATION OF WASTES IN STABILISATION POND

The treatment mechanism in a stabilisation pond depends upon mutually beneficial relationship (Figure-1)

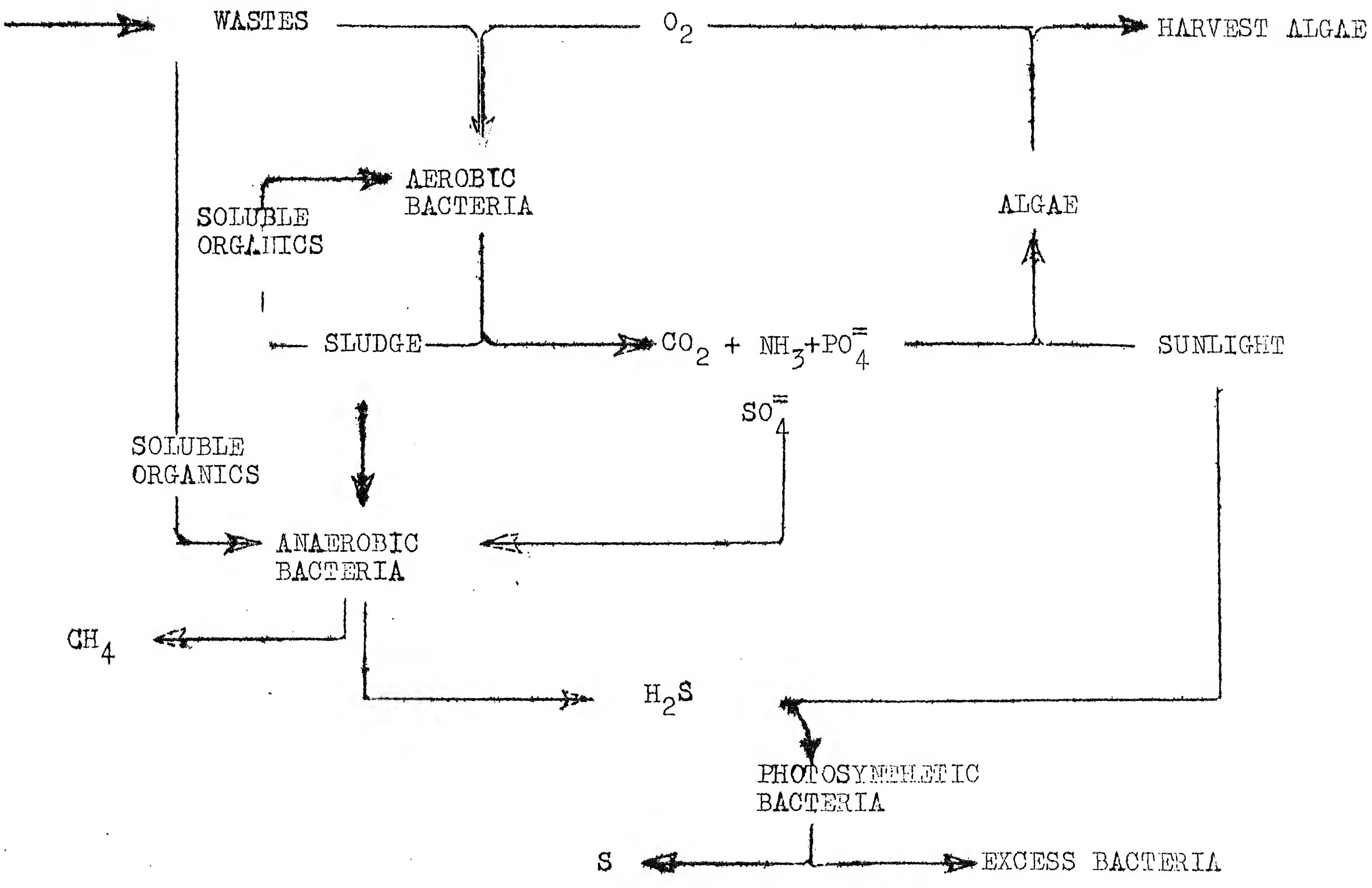

FIGURE - 1 PROCESSES TAKING PLACE IN THE STABILISATION POND

that exists between algae and bacteria; each giving to the other, what the other needs. Under favourable conditions, bacteria oxidise the organic matter present in the wastes aerobically resulting into the production of carbon dioxide, ammonia, phosphate and water etc. which incidentally happen to be the essential nutrients in presence of sunlight for algal photosynthesis. Algae utilise these simpler end products of the bacterial decomposition and with the help of solar energy synthesise more algae; simultaneously releasing oxygen which can be utilized by bacteria. The excess quantity of algae and bacteria produced in the process pass out with the effluent. Out of total oxygen supplied to pond-effluent only very small fraction is consumed by algae themselves for respiratory needs. In completely aerobic ponds the amount of oxygen production is much more as compared to algal respiratory consumption and thus aerobic condition is normally maintained throughout. Conditions might turn anaerobic in a facultative pond under unfavourable conditions.

If sufficient oxygen is not available particularly in the bottom layers of a pond, anaerobic or facultative bacteria obtain the required oxygen from chemical compoundslike nitrates and sulphates and produce various volatile acids which are, in turn further degraded to

methane and carbon dioxide by what are known as methane bacteria.

2.2.1 AEROBIC OXIDATION

Disregarding phosphorus, sulfur and trace elements, the oxidation of organic matter has been found experimentally to follow the reaction (17)

$$C_{11}H_{29}O_7N + 14\ O_2 + H^+ \longrightarrow 11CO_2 + 13H_2O + NH_4^+$$

Ammonia is rarely oxidised to nitrate in stabilisation ponds because it is either assimilated by algae, lost to the air or precipitated during periods of high pH before nitrification can become established.

2.2.2 OXYGEN PRODUCTION THROUGH PHOTOSYNTHESIS

Photosynthesis is the major source of oxygen for aerobic oxidation in stabilisation ponds since atmospheric reaeration is negligible as compared to this. Oswald (18) has given the following reaction for the composition of algae.

$$NH_4^+ + 7.6\ CO_2 + 17.7\ H_2O \longrightarrow C_7H_{8.1}O_{2.5}N + 7.6\ O_2 + 15.2\ H_2O - 886\ \text{K cal.}$$

About 1.67 mg of oxygen are liberated for each mg of algae synthesised (19).

2.2.3 CONVERSION OF SOLAR ENERGY

Only a small fraction of solar energy received on a pond surface is converted into chemical energy and gets fixed in new algal cells. The energy so converted, can be computed in terms of calories per litre per day by the equation given below (5).

$$H = Y_c \, h'$$

where : H = Energy in terms of calories per litre per day.

Y_c = Yield of algae in mg/litre/day

and h' = Unit heat of combustion per mg of algal species involved.

The value of h' can be computed by the empirical relation

$$h' = \frac{R}{7.89} + 0.4$$

where $$R = \frac{100\left[2.66\ (\%C) + 7.49\ (\%H) - (\%O)\right]}{398.9}$$

C, H, O can be computed on ash free weight basis for a given species. Experimentally h' has been found to be about 6 calories per milligram for sewage grown algae (5). The value reported from controlled experiments (21) show that the efficiency of conversion of solar energy is around 4 percent under normal conditions.

2.2.4 ILLUMINATION REQUIREMENT FOR PHOTOSYNTHESIS

It is a layman belief that high intensity of sunshine is necessary for algal photosynthesis. Actually it is not like that, rather the requirement varies from species to species. For a species like Anacystis, the saturation level is well below 1000 foot-candles or less than 1/10 of full sunlight. The light saturation intensity for Chlorella is 600 foot-candles only, where as for Euglena the optimum is 2000 foot-candles. It can therefore, be stated that very high intensity light is not normally needed for successful waste treatment. Adequate light energy is normally available for photosynthesis any where in India including its northmost parts (5).

2.3 SPECIES OF ALGAE IN STABILISATION PONDS

Totally, over 17000 species of algae are now

known (5) but only relatively few of them are important for public health engineers.

Of particular significance in waste stabilisation ponds are the commonly found green (Chlorophyta) and blue - green (Cyanophyta) algae.

Blue-green algal mats frequently develop in ponds during summer months. Euglena species show a high degree of adaptability to various pond conditions and are present during all seasons and under most climatological conditions. Probably next in adaptability are Chlamydomonas, Ankistrodesmus, Scenedesmus and Chlorella. Chlorella has relatively the maximum oxygen production capacity and is, therefore, the most desirable algae in stabilisation pond. Fitzgerald et al. (14) conclude that the most numerous algae which grow on sewage are normally species of Chlorella, Scenedesmus and Euglena. Jayangouder(20), in a quantitative studies of the dominant and sub-dominant algal flora of the pilot lagoon at Ahmedabad during the monsoon and post-monsoon seasons of 1962 found that the dominant species was Chlorella pyrenoidosa. But predominance of one species over the other varies from season to season. This statement is supported by Round (21), who states that species are controlled by season and

geographical location as light intensity and temperature are important factors in the growth of different species.

2.4 HEALTH ASPECTS

As per studies made by number of workers a properly designed and operated stabilisation pond system would give an equally good effluent, if not better than what is expected from the conventional sewage treatment plant with respect to health aspects. In fact stabilisation ponds are often reported to be giving higher percentage removals of indicator bacteria and pathogens than conventional plants. In studies made by CPHERI (5) on a pond treating 1/2 mgd of municipal sewage at Nagpur it was found that the effluent was free from bacterial pathogens, cysts of *Entamoeba hystolytica* and helmith eggs. *E. coli* removal efficiency as high as 99.99 percent has been reported by Arceivala *et al*. (5). The reasons for die-away of coliforms and bacterial pathogens in stabilization ponds are believed to be mainly due to the prevalance of high pH value in excess of 8 and even as high as 10.5 at certain hours generally in the afternoons (22). The die-away might also be due to release of anti-bacterial substances by some algae (23). As reported by Arccivala *et al*. (5) intestinal pathogens

belonging to Salmonella and Shigella groups were found to be completely absent during testing period (Feb. 1969 - Aug. 1969) in a full scale studies of stabilisation pond at Bhandewadi, Nagpur. The percentage reduction of coliforms and fecal streptococci were in the ranges of 99.7 to 99.9996 and 99.0 to 99.9998 respectively. In laboratory and field scale studies made by Davis and Gloyna (24) it was observed that enteric bacteria & other pathogens die faster in contact with mixed algal culture, than with pure algal culture. The die-rate constant became higher when pre-anaerobic conditions were employed. Virus removal studies carried out by CPHERI Nagpore (5) showed that in waste stabilisation ponds over 90 percent removal of enteric viruses could be obtained.

Experience with working of ponds in India and in other countries (25) has shown that the mosquito breeding is directly proportional to the extent of aquatic vegetation and floating matter in ponds, both of which can be controlled by good design, proper operation and maintenance.

It can therefore, be stated that stabilisation ponds are in many respects better than conventional treatment plants with respect to health aspects.

2.5 VARIOUS METHODS FOR HARVESTING OF ALGAE

It has already been mentioned that harvesting of algae from stabilisation pond effluent is difficult due to their microscopic physical size, low specific gravity and dilute suspensions. However, various methods have been tried by different workers and a brief review of the same is given here.

The processing of algae needs the following steps (11) :

1. Initially concentrating the algal suspension,
2. Dewatering and concentrating the resulting slurry,
3. Drying the dewatered algae for storage and handling.

Theses three steps are necessary because it is neither technically nor economically feasible to bring the algae from their dispersed state in the culture to a finished dried product in one operation only.

After dewatering, a slurry of about 8-15% solids content can be achieved (4).

Some of the methods tried by different workers

(11, 12, 26, 27) for harvesting of algae are :

i) Centrifugation

ii) Chemical precipitation

iii) Filtration

iv) Flotation

v) Ion Exchange

vi) Passing through charged zones

vii) Ultrasonic vibration

viii) Microstraining

2.5.1 CENTRIFUGATION

In an experimental study made by Golueke & Oswald (11) it was observed that the removal of algae from algal suspension of 200 mg/l ranged from 84 percent at a throughput rate of 100 gpm to about 64 percent at 385 gpm at rotational velocities of 3000 and 3300 rpm. respectively. It was noticed that the disc angle of the centrifuge also affects the separation at throughput rates greater than 300 gpm. At throughput rate of 385 gpm, removal with disc angle of 45° was 52-64 percent, while with 55° it was 74 percent. Power requirements varied inversely with algal- concentration. For example, at a throughput rate of 300 gpm and the algal concentration of 86 mg/l, 7.64×10^3 KWH were required; whereas with algal concentration

of 295 mg/l. The power requirement was only 2.64×10^3 KWH for processing one ton of algae.

Although centrifugation offers the advantage of simplicity, continuity in operation and the production of material high in quality without the need of any chemical, it has certain obvious disadvantages which outweigh the advantages. One is the high cost of the centrifuge itself (a centrifuge for a throughput rate of 400 gpm cost $ 50,000 in 1963-64). and the other disadvantage is the relatively high power consumption. Large scale harvesting through centrifugation therefore, appears to be out of question in developing countries.

2.5.2 CHEMICAL PRECIPITATION

Removal through chemical precipitation involves the addition of reagents such as aluminium sulfate (filter alum), lime, or organic cationic flocculents, acids, etc. when coagulation is induced by addition of a chemical reagent, the addition of the reagent is followed by a brief period of rapid mixing and then five to ten minutes of gentle stirring to develop floc particles of sufficient size and density to permit rapid sedimentation and then after subsequent removal of flocculated material.

Although separating algae with the use of alum or lime is relatively cheap the harvested product contains either aluminium or lime which precludes the product to be utilised for other beneficial purposes. Saini (8) reported that algae harvested through alum precipitation could not be digested anaerobically. Another disadvantage accompanying the use of lime is the high pH of the effluent which makes it undesirable for direct discharge into streams or other bodies of water, or for use in industries (11). On the other hand the pH is generally very low when alum is used. Consequently an additional expenditure would be required for waste water conditioning. This method, therefore, has many limitations against large scale use. Golueke and Oswald (11) further report that the use of organic reagents 'Sondelite' and 'Purifloc 601 and 602' gave better results but these chemicals were very costly as well as scarcely available. It may be noted here that these chemicals are not available in India.

2.5.3 FILTRATION

Golueke and Oswald (11) tried filtration on laboratory scale using a Buchner funnel and with an Oliver filter leaf 3 cm in diameter. Complete removal

was reported with diatomaccous earth, corn starch and calcined rice hulls as filter aids. It was observed that all filter media including some types of filter-papers, fine mesh metal, nylon, cotton and woolen screens of wide varieties were ineffective in absence of filter aids. It was further reported by Gloyna et al. (28) that minimum cost for filter aid was of the order of $ 110 per million gallons of suspensions.

Biological filters were effective but the throughput rate was very low. It was thus concluded that filtration would not be an economically feasible method for harvesting of algae.

2.5.4 FLOTATION

Removal of algae by flotation too has been tried by number of workers. Golueke and Oswald (11) used 18 different flotation reagents but most of them were ineffective excepting the two. Levin et al. (29) observed that harvesting, by flotation was a function of pH, aeration rate, aerator porosity, feed concentration and height of foam in the processing column. They also report that good removal could be obtained only below pH 4.0 which appears to be a drawback for the process as normal pH of the pond effluent remains 8 or above.

Ramchandran (12) and Kumara Sastry (13) used foam flotation for algal-harvesting on batch and continuous process. Both of them used an imported cationic surfactant, hexadecapyridinium chloride ($C_{21}H_{38}$ Ncl) which is very expensive and is not available in India. Ramchandran reports that the best removal (about 75%) could be achieved with surfactant dose of 20 mg/l, airflow rate of 1.5 volume of air per unit volume of liquid per minute (VVM) and pH 3.0. Similar results were obtained by Kumara Sastry. Sastry also tried with indigenous surfactants such as Acinol CDMB, Acifix liquid, Dex = 2, Saponin etc. but the effectiveness of these reagents was very poor and was not comparable with the previous one.

Necessity of costly surfactants (like Hexadecapyridinium chloride), reduction of pH of the suspension as low as 3.0, and aeration of the system @ 1.5 VVM for removal of algae from pond-effluent altogether render the process rather expensive and discourage its adoptation on field scale.

2.5.5 ION EXCHANGE

Golueke et al.(30) in their studies found that algae could be removed by passing an algal suspension through a column either of weak or strong cation-exchange

resin, although the latter being more effective.

Mechanism of removal involved flocculation that resulted from changes in surface charge of the algal cells brought about by the charge of the resin;this was demonstrated by the failure of the exchange columns to remove algae after their exchange capacity had been exhausted. Their ability to remove the algae became progressively less after each regeneration. The draw back of the process was that the regeneration of columns could be accomplished only with H^+. The addition of Na^+ or any cations other than H^+ effectively interferred with algal - removal capacity.

These studies were carried out on laboratory scale and further studies would be necessary to explore its possibility for field-scale size.

2.5.6 PASSING THROUGH CHARGED ZONES

Algae exhibit a negative surface charge (32). Based on this property it was hypothesised that they could be made to migrate towards the cathode of an electrolytic cell. Experiments to this effect were carried out by Golueke *et al.* (11). on laboratory scale. Aluminium, copper and carbon were used as electrode material

either in pairs of the same or of different materials. Distance between electrodes varied from 1/8 to 1/12 inch and current varied from 0 to 900 milli ampere. Throughput rates varied from 0.05 to 1.2 gpm per $ft.^3$ of cell volume. Excellent separation occurred with aluminium or copper electrodes because of good floc formation by the release of copper and/or aluminium and subsequent formation of hydroxides of copper and/or aluminium. Unfortunately carbon electrodes could show little or no response.

2.5.7 SONIC VIBRATION

It was hypothesised that, if cells were compelled to come in contact with each other by some force and thereby have their surface charges neutralized, they, then would adhere to each other. Eventually they might form clumps of cells sufficiently large for settling or at least large enough for easy removal by conventional screening methods. Golueke *et al*. (11) tried to prove this hypothesis by exposing the algal culture to ultrasonic waves of 15000 cps or higher. But the result was just the reverse;the cells, instead of being clumped together, dispersed effectively.

2.5.8 MICROSTRAINING

Berry (31) conducted various experiments with

microstrainers at varying flow rates and varying speeds of the drum. He reported fairly successful removal of filamentous algae but the removal of planktonic forms was only indifferently successful. Microstraining is based on development of microfabrics of stainless steel. Further reducing the pore-size of the microfabrics might remove the planktonic forms but this would create the problems of clogging and thus reduction in rate of filtration. Golueke _et al_. (11) report that filter aids, showed some improvement in removing planktonic forms, but flow rate was appreciably reduced. Development of effective microstrainers is therefore necessary before adopting them for harvesting sewage grown planktonic algae, otherwise the use of filters would make the process highly uneconomical.

2.6 CLOSURE

Golueke _et al_. (11), comparing the various merits and demerits of above discussed methods, report chemical precipitation to be comparatively successful and feasible process. As has been discussed earlier, this method involves the necessity of various chemical reagents that make the method expensive and the harvested algae

less useful. Attention and efforts should be diverted towards exploring economical and simple method that would avoid the necessity of any chemical what-so-ever.

The present study has been undertaken with this view in mind.

CHAPTER III

MATERIALS AND METHODS

3.1 INTRODUCTION

Source of algal-culture for various experiments was the effluent from stabilisation pond of I.I.T. Kanpur-Campus. The characteristics of the pond and its effluent are given in Table - 1. The mixed algal concentration has been found to vary from 76 mg/l in winter to 430 mg/l in summer as determined by Spectronic-20*. All the experiments were conducted inside the institute laboratory at room temperatures varying from 15°C to 38°C. No attempt was made to adjust the pH. However, the record for the pH was maintained and its value has been reported with respective results.

3.2 MICROSCOPIC STUDIES

To identify the species of algae present in pond-effluent, microscopic studies were carried out and the identification effected according to Standard Methods. The identification was further confirmed by algalogist at CPHERI- Nagpur. The species observed are presented in

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* A spectrophotometer ; path length 1 cm. (Bausch & Lomb)

TABLE 1

CHARACTERISTICS OF STABILISATION PONS (I.I.T.KANPUR)

(Reference - 5, 8, 40 and 41)

1. GENERAL CHARACTERISTICS

1.1	Dimension in metres (each)	91.44x60.96x1.37			
1.2	Area in hectare (each)	0.55			
1.3	Population Serving	6000			
1.4	Daily Flow (million litres)	2			
1.5	Detention Time (days)	4.5			
1.6	Percent BOD Reduction	83.3			
1.7	Sludge Accumulation(M^3/capita-year)	0.31			
1.8	Provision of Grit Chamber	Nil			
1.9	Mean Air Temperature (°C)	Jan.	May	Aug.	Nov.
		14.9	34.1	29.0	22.9
1.10	Mean Monthly Wind Speed (Km/hr)	3.7	12.71	10.30	4.02
1.11	Latitude	26° 26^m N			
1.12	Average Solar Radiation (gm calories/cm^2-day)	300			
1.13	Approx. duration of sun-shine (hrs. min)	22 Dec.	21 March 23 Sept.	22 June	
		10-30	12-06	13-48	

TABLE 1 (CONTD.)

2. INFLUENT CHARACTERISTICS

2.1	BOD_5 (mg/l)	160-180
2.2	Organic loading (kg/hectare-day)	465
2.3	Suspended Solids (mg/l)	120
2.4	Ammonia Nitrogen (mg/l)	6.5
2.5	Organic Nitrogen (mg/l)	8.0
2.6	Total Phosphates (mg/l)	5.2
2.7	Chloride (mg/l)	65.8
2.8	pH	7.9

3. EFFLUENT CHARACTERISTICS

3.1	Algae Concentration (mg/l)	76-430
3.2	pH	8.7-10.0
3.3	Ammonia Nitrogen (mg/l)	2.83
3.4	Organic Nitrogen (mg/l)	5.20
3.5	Total Phosphates (mg/l)	2.80
3.6	DO (mg/l)	8.90

TABLE 2

SPECIES OF ALGAE OBSERVED IN POND-EFFLUENT

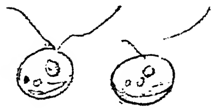
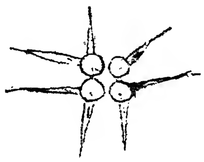
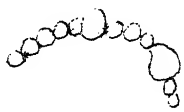
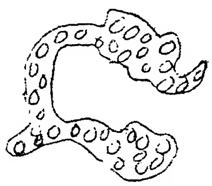
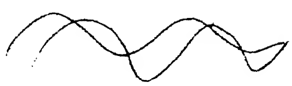
1. GREEN ALGAE (CHLOROPHYTA)		
1.1 Chlorella		Predominant
1.2 Chlamydomonas		Good Number
1.3 Micractinium		Few
2. BLUE GREEN ALGAE (CYANOPHYTA)		
2.1 Anabaena		Good Number
2.2 Anacystis		Very few
2.3 Phormidium		Rare
2.4 Spirulina (orthospira)		Quite Good Number
3. DIATOMS (BACILLARIOPYTA)		
3.1 Navicula		Rare

TABLE 2 (CONTD.)

4. FLAGELLATES (EUGLENOPYTA)

4.1 Euglena		Few

N.B : In addition to algae Protozoa (Paramecium) were observed in quite good numbers.

Table 2 from where it can be seen that Chlorella was the most predominant species.

3.3 CALIBRATION CURVE (ALGAL-CONCENTRATION VS. ABSORBANCE)

The optimum wave length for mixed algal-suspension was determined to be 430 $m\mu$ on "Spectronic-20" at path length of 1 cm. About 2 litres of the algal-culture was centrifuged at 8000 rpm for ten minutes in laboratory centrifuge. A thick suspension was prepared by re-mixing the pellets formed, in distilled water. Twentyfive ml. of the suspension was taken in a crucible and dried in hot air oven at a temperature of 103°C for 24 hours and dryweight determined after proper desiccation. With other portion of the concentrated suspension different suitable dilutions were prepared with distilled water. Absorbance of each suspension was found at pre-determined optimum wavelength (430 $m\mu$). The calibration curve prepared is shown in Figure - 2. This figure shows the relation between dry-weight-algal-concentration and absorbance at pathlength 1 cm and wavelength 430 $m\mu$.

3.4 EXPERIMENTAL SET-UP

The main experimental setups are presented in Figure 3 and 4. The first set-up consists of a domestic

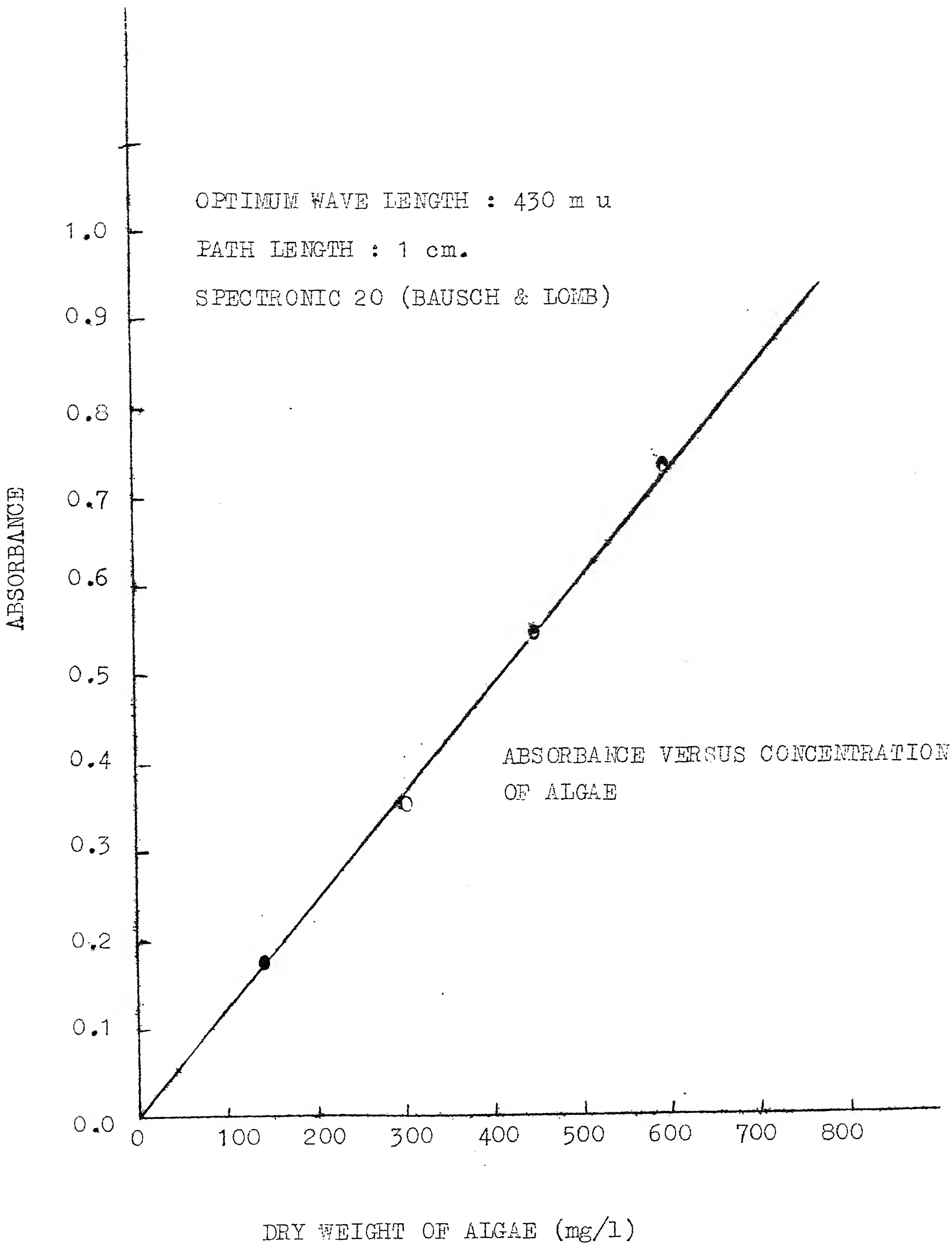


FIGURE : 2 CALIBRATION CURVE

blender of one litre capacity (Table 4) with an energy meter (Table 5) of sensitivity, upto the order of 5.5×10^{-6} KWH. connected in series. The blender consists of three different speed control device. It was used for blending various algal-suspensions at various speeds. The corresponding electrical energy consumption each time was measured through energy meter. Figure - 4 consists of graduated cylinders which were used as sedimentation chambers for blended and unblended algal - suspensions. As shown in Figure - 4, the first and fourth cylinder from the left consists of freshly mixed unblended (control) and blended algal suspension. Cylinder No. 3 and 5 through 8 contain algal - suspension to which little or no blending has been applied. Cylinders 9th onward contain nicely blended suspension. It can be seen from Figure - 4 that algae float on the surface in some of the cylinders while in other they have settled at the bottom. Necessary discussion about this phenomenon has been presented later.

Another means of inducing agitation to algal-suspension was its recirculation through a small size centrifugal pump (Table - 3). The electrical energy consumption was measured with the same energy meter referred above. The algal-suspension after recirculation

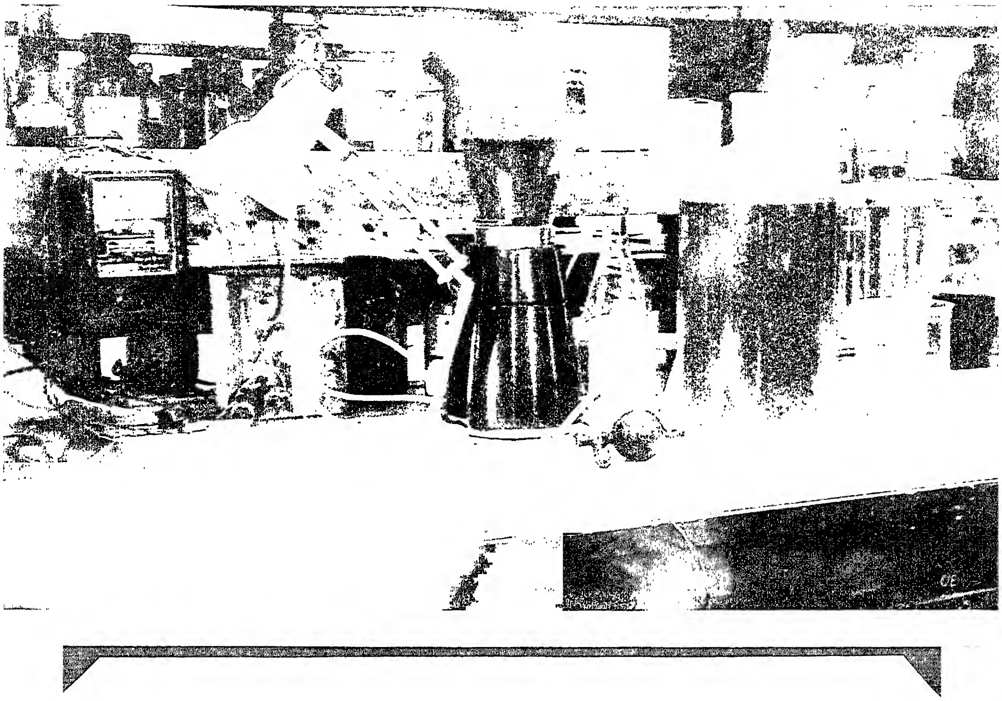


FIGURE 3, EXPERIMENTAL SET-UP (BLENDING)

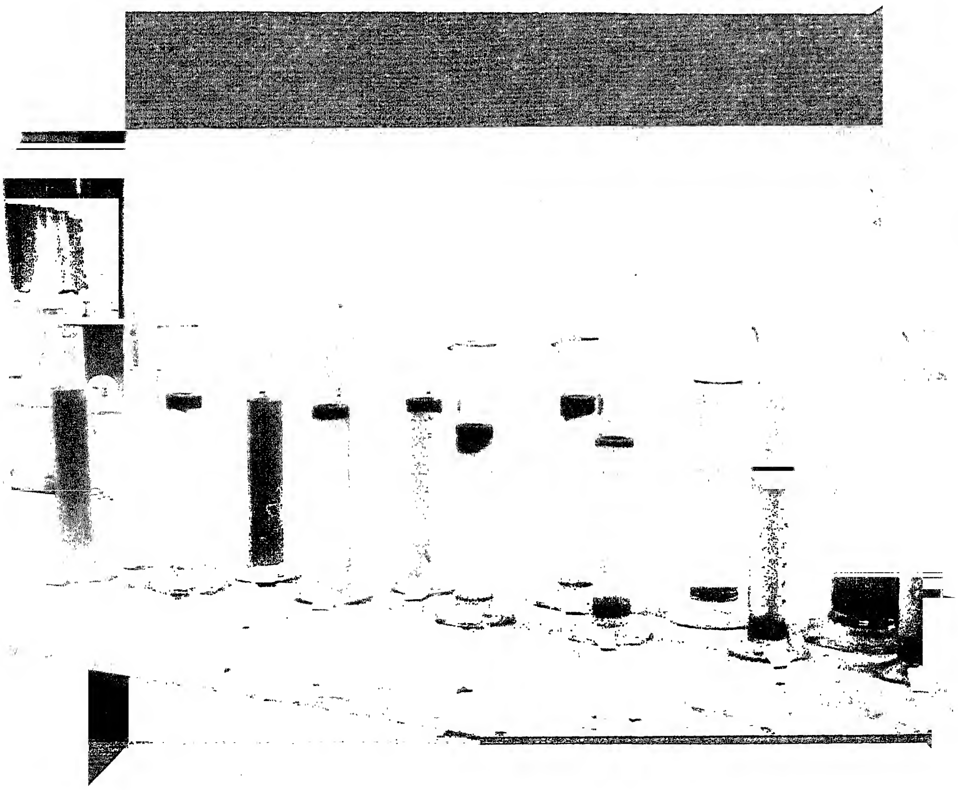


FIGURE 4, EXPERIMENTAL SET-UP (SETTLING)

TABLE 3

PUMP(CENTRIFUGAL)

SPECIFICATION

SCM	:	MOTOR
CYC	:	50
FLC	:	0.4A
RPM	:	4000
RATING	:	Constant
SER.NO.	:	3405

SOM ENGG. CORPORATION INDIA

POWER

0.1 KW

or

0.134 hp.

or

10^9 ergs/sec.

TABLE 4

BLENDER

SPECIFICATION

BAJAJ SENIOR MIXER

WATTS : 350, VOLTS 230 AC/DC

CAPACITY : 1 LITRE

BATCH NO. 4690148

SER. NO. 413

BAJAJ ELECTRICAL LTD. INDIA

SPEED (UNLOADED)			POWER (LOADED)
	RPM*		KW
I-	5000	-	0.25
II-	5400	-	0.33
III-	5750	-	0.40

---

* Measured with "STROBOTAC" (electronic stroboscope) Type 1531 - AB. manufactured by General Radio Company, West Concord, Massachusetts, U.S.A.

TABLE 5

ENERGY METER

SPECIFICATION

SINGLE PHASE A/C METER

AMP. MAX : 10

TYPE : L

VOLTS : 230

CYC. : 50

REV. PER KWH : 1800

NO. : 2157843

CHAMBERLAIN & HOOKHAM LTD.

SENSITIVITY

5.5×10^{-6} KWH

for varying time was also kept in measuring cylinders in similar fashion as shown in Figure - 4.

Detail specifications about pump, Blender and energy meter used, are given in Tables 3, 4 & 5 respectively. Other details and the experimental results are presented in Chapter IV.

3.5 METHOD FOR CALCULATING SHEAR GRADIENT 'G' AND SHEAR STRESS "τ"

The agitation applied to any real fluid imparts it velocity gradients and the work done by the shearing stresses generated is dissipated in the fluid. The velocity gradients throughout a mixing chamber vary considerably in magnitude, but under steady conditions of work input there is a mean velocity gradient which corresponds with the mean value of work input per unit of time per unit volume, ϕ_m, throughout the tank. Camp and Stein (43) have shown ϕ_m, the work of shear per unit volume per unit of time at a point, to be the dissipation function and have developed the following specific relationship for the root-mean-square temporal velocity gradient which is given the symbol "G" as shear gradient.

$$G = \sqrt{\frac{\phi_m}{\mu}} = \sqrt{\frac{P}{\mu V}} \qquad \text{(i)}$$

where P = Power input (dyne cm/sec) to the fluid

μ = Viscosity of the fluid (dyne sec/cm^2)

V = Volume (cm^3) of the fluid to which the power input is applied

G = Shear gradient (sec^{-1})

According to Camp and Stein the relationship (i) is of general validity in both viscous and turbulent flow.

Shear stress $\tau = \mu G$ dyne/cm^2 (ii)

CHAPTER IV

EXPERIMENTS AND RESULTS

4.1 GENERAL OUTLINE

As mentioned earlier the source of algal- suspension for various experiments conducted for this work was the effluent from I.I.T. - Campus stabilisation pond and for every experiment fresh sample was collected each time. Initial algal-concentration therefore, has been different for different experiments. It would be ideal to conduct various experiments with pure cultures of algal having uniform concentrations. However, the studies were carried with naturally available mixed algal suspensions because of the need for future practical application.

The various experiments and results are arranged in a sequential order and presented below. It may be noted that experiments have been repeated number of times and only the representative results are presented here.

SEQUENCE OF EXPERIMENTS

(i) Algal Removal Under Natural Conditions

(ii) Algal Removal by Slow Agitation

(iii) Algal Removal by Recirculating through a Pump

(iv) Algal Removal by Blending

(v) Viability of Harvested Algae

(vi) Mechanism of Removal

4.2 ALGAL REMOVAL UNDER NATURAL CONDITIONS

4.2.1 NATURAL SETTLING

With the purpose of studying the natural removal of algal-cells, from pond effluent, the freshly collected samples were simply kept in graduated cylinders for quiescent settling under darkness and light. The efficiency of removal (based on percent settling) was found at time intervals of 12, 24, 36 and 48 hours. From the results presented in Table 6, it can be seen that the efficiencies of removal are very poor and even the maximum efficiency is only 20% at the end of 48 hours, in case of dark-storage.

4.2.2 NATURAL FLOTATION

During previous experiment it was observed that most of the algal-cells kept floating to the surface. An experiment was therefore designed to study the feasibility of removal of algae through natural flotation. The algal suspension was taken in a long glass column with outlets

TABLE 6

ALGAL REMOVAL UNDER NATURAL CONDITION

INITIAL CONCENTRATION : 225 mg/l, pH-9.4

SETTLING TIME (HRS)	PERCENT REMOVAL	
	LIGHT*	DARKNESS
0	NIL	NIL
12	5.0	8.7
24	7.5	15.5
36	10.8	18.5
48	12.5	20.6

* FLUORESCENT TUBES

Number	8
Wattage	40
Length	4 Ft.

at various depths (Table 7). The concentrations of algae were determined at various time intervals and at different depths by withdrawing samples from each outlet. Results are presented in Table 8.

During the course of experiment some of the algae which were uniformly distributed in the column, moved towards the surface while some settled towards the bottom. Based on initial concentrations of algae there was almost ten fold increase in concentration at the top while the algal concentration at the bottom more or less remained the same at the end of 48 hours with an initial reduction for a short period. However, attempts to harvest the algae from top portion met with failure because of the reasons as given below.

(i) The highly concentrated top layer of algae was very thin.

(ii) They got either stuck to the walls or redistributed into the liquid even with slightest disturbance.

Further investigations to put this phenomenon for practical use failed and the attempts were therefore given up.

TABLE 7

DETAILS OF PYREX GLASS COLUMN USED IN NATURAL FLOTATION

COLUMN LENGTH : 55 cm.

COLUMN DIA : 6.5 cm.

OUTLET NO.	DEPTH FROM TOP (cm)
O (TOP)	NIL
I	15
II	30
III	45
IV (BOTTOM)	55

TABLE 8

REMOVAL OF ALGAE UNDER NATURAL FLOTATION AT VARIOUS DEPTH AND TIME

TIME (HRS)	ALGAL CONCENTRATIONS (mg/l)				
	OUTLET NO.				
	0	I	II	III	IV
0	225	225	225	225	225
2	960	335	325	240	195
4	1000	255	230	195	165
6	1060	230	230	185	165
8	1080	-	215	180	178
20	-	-	150	145	180
22	2140	-	125	125	187
24	2200	-	115	115	185
48	2100	-	135	125	200

4.3 ALGAL REMOVAL BY SLOW AGITATION

Since it was difficult to remove algae from top portion during natural flotation study trials were aimed at inducing settlement of algae. As algae were in suspension it was felt that agitation and mixing might promote agglomeration and quicker settling.

The pond effluent was agitated slowly by stirrer in the Jar Test Apparatus. The agitation was carried out at 20, 40, 60, 80 and 100 rpm for 20 minutes in each case. The algal suspension afterwards was kept under quiescent condition for 24 hours. The efficiency of removal and other experimental results are presented in Table 9. The efficiency of removal was quite low, the maximum being 53% only.

4.4 ALGAL REMOVAL BY RECIRCULATING THROUGH PUMP

During some trials for growing algae under continuous recirculation of the culture with intense light it was observed that the algae showed a tendency to settle down more and more after every passage through a small water-recirculating centrifugal pump (Table 3). This phenomenon was investigated in some detail and the experiments are described here.

TABLE 9

EFFICIENCY OF REMOVAL BY SLOW AGITATION

Initial Algae Concentration : 160 mg/l

Effluent Volume Under Operation : 500 ml.

MIXING SPEED	PERCENT REMOVAL
NIL (CONTROL)	15.3
20 rpm	22.1
40 "	25.0
60 "	37.5
80 "	37.5
100 "	53.0

The above noted phenomenon was observed under light but it was not certain whether light had any influence for this to occur. An experiment was therefore, designed to study the effect of light on algal removal by recirculation through pump. The algal suspension was recirculated through pump both in presence and absence of light for varying number of times. The suspension afterwards was kept in 100 ml graduated cylinders under quiescent condition. The percent removal (based on algal settling) was calculated at the end of 24 hours. From the experimental results presented in Table - 10 it can be seen that the presence of light did not have any effect on algal removal. The efficiency is better in the absence of light.

Since light did not have any positive influence on the algal-removal it was eliminated in further experiments.

As the efficiency of removal more or less varied with the number of passages through the pump it was decided to measure the corresponding electrical energy and correlate the efficiency of removal with electrical energy consumed in the process of recirculation. An energy meter (Table 5) was incorporated in the system which could measure the electrical energy upto an accuracy of 5.5×10^{-6} KWH. Similar experiments were conducted with initial algal concentrations

TABLE 10

EFFECT OF LIGHT ON ALGAL REMOVAL BY RECIRCULATION THROUGH PUMP

Initial Concentration of algae 96 mg/l
pH 9.2

Settling Time 24 hours

Condition of Recirculation		Number of Recirculation	Percent Removal
PUMP	LIGHT		
	CONTROL		5.0
Yes	No	4	28.4
Yes	No	8	33.3
Yes	No	12	38.3
Yes	Yes	4	25.0
Yes	Yes	8	23.4
Yes	Yes	12	28.4

of 225, 195, and 107 mg/l. In these experiments instead of measuring the number of recirculations, the electrical consumption as KWH per litre of algal suspension was measured in each case.

With an initial concentration of algae of 120 mg/l an experiment was conducted to find optimum settling time. The settling time was determined by plotting the efficiency of removal against varying settling time after the recirculated sample was kept in the graduated cylinders. The experimental results for this is presented in Figure 5. It was found that after 20 hours there was not much increase in algal settling.

The energy meter recorded the total energy input and eighty percent of the recorded consumption was assumed to be the input into the system. The experimental results are presented in the form of "Percent Removal Versus Energy Input (KWH/litre) in Figure 6. It can be seen that the relationship between percent removal and energy consumption (KWH/litre) are exponential in nature and more or less similar for all the three concentrations. However, the maximum removal was only upto the order of 50%. It was therefore planned to investigate if the efficiency of removal could be increased further. There was not much scope with the pump since it could be only operated at a constant speed.

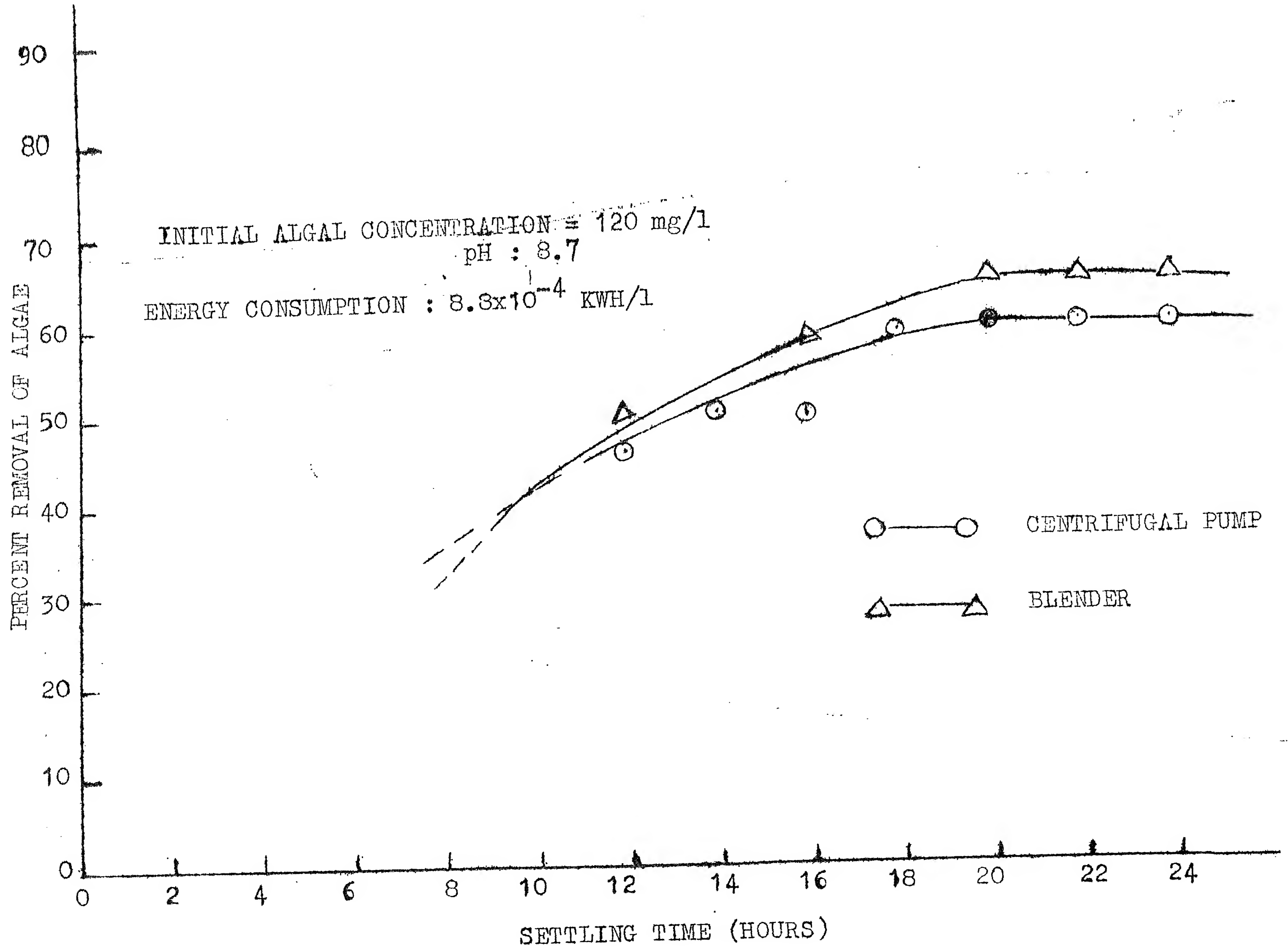


FIGURE - 5 PER CENT REMOVAL VERSUS SETTLING TIME

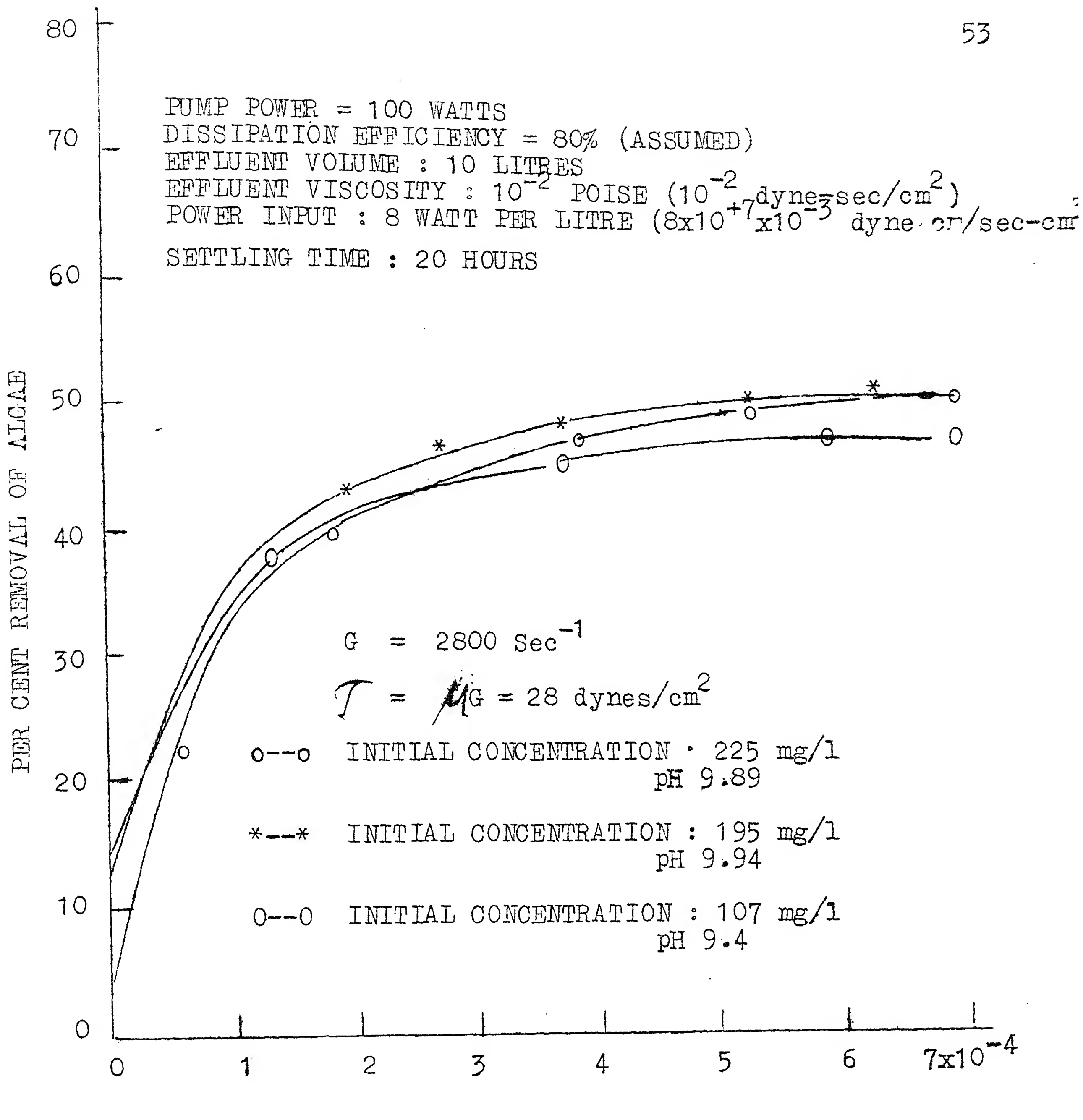


FIGURE - 6 PERCENT REMOVAL VERSUS ENERGY INPUT PER LITRE

WITH PUMP

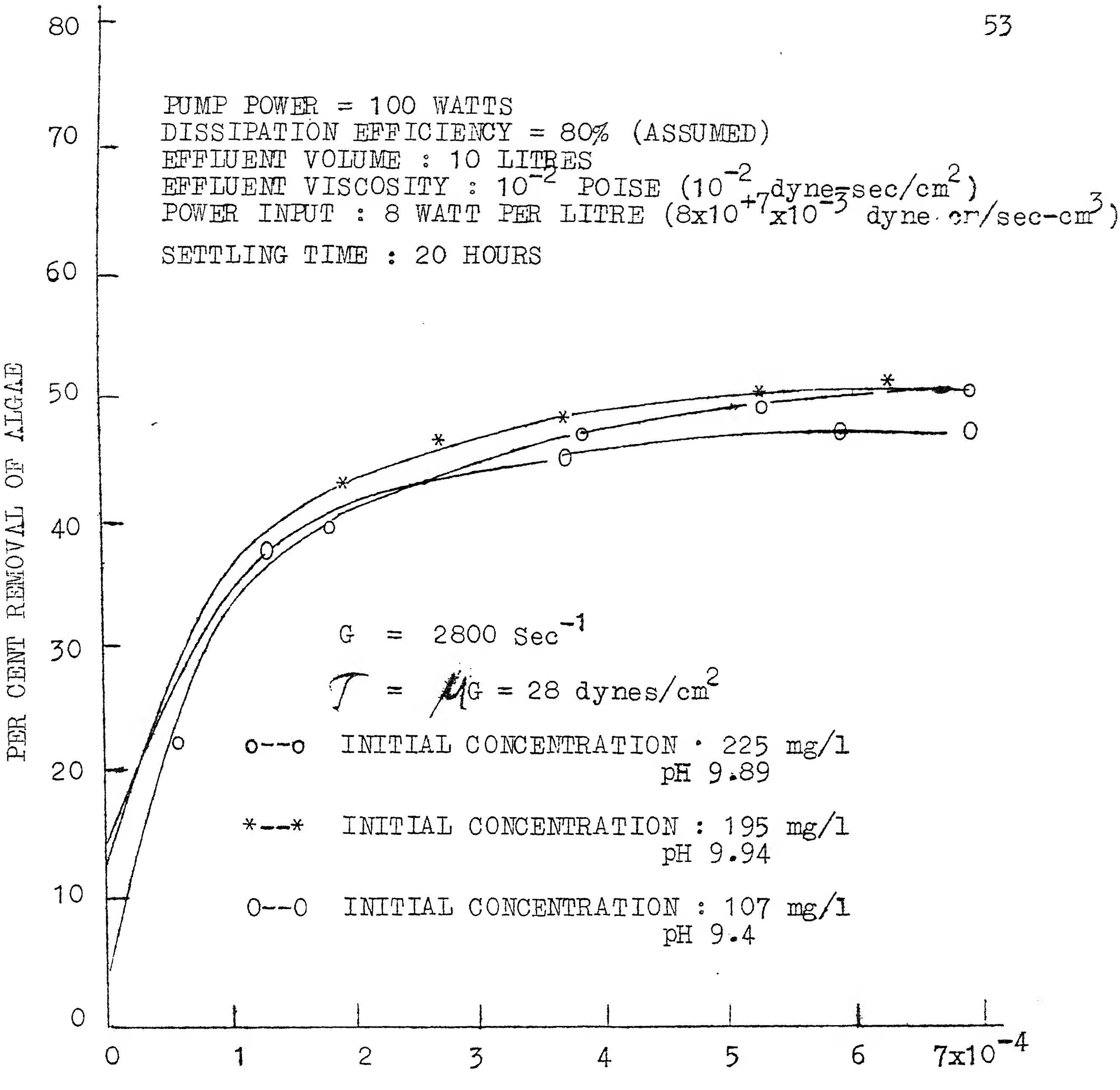


FIGURE - 6 PERCENT REMOVAL VERSUS ENERGY INPUT PER LITRE WITH PUMP

It was also guessed that some sort of shearing action was operative in actuating this phenomena; the next device (blender) was brought under study.

4.5 ALGAL REMOVAL BY BLENDING

The detail specifications of the domestic blender used in this experiment are given in Table 4. This particular blender has three different speed control device. Before actually starting the experiment its three different speeds were measured with STOBOSCOPE and its corresponding power with energy meter and stopwatch. For algal removal - study the experiments were first carried out at the lowest speed of the blender. In this case also the investigation was made with three different algal-concentrations and the same graduated cylinders were used for settling. Here also the settling time was 20 hours (Figure 5) as before. Here the rate of power input was higher than that with pump. It should be noted that the energy input in either case was assumed to be 80 percent of energy consumption recorded by energy meter (Table 5). The experimental results are presented in Figure 7. It can be seen that the efficiency curve becomes asymptotic after attaining a value of about 80%. The maximum removal efficiency in this is reasonably higher than that with pump.

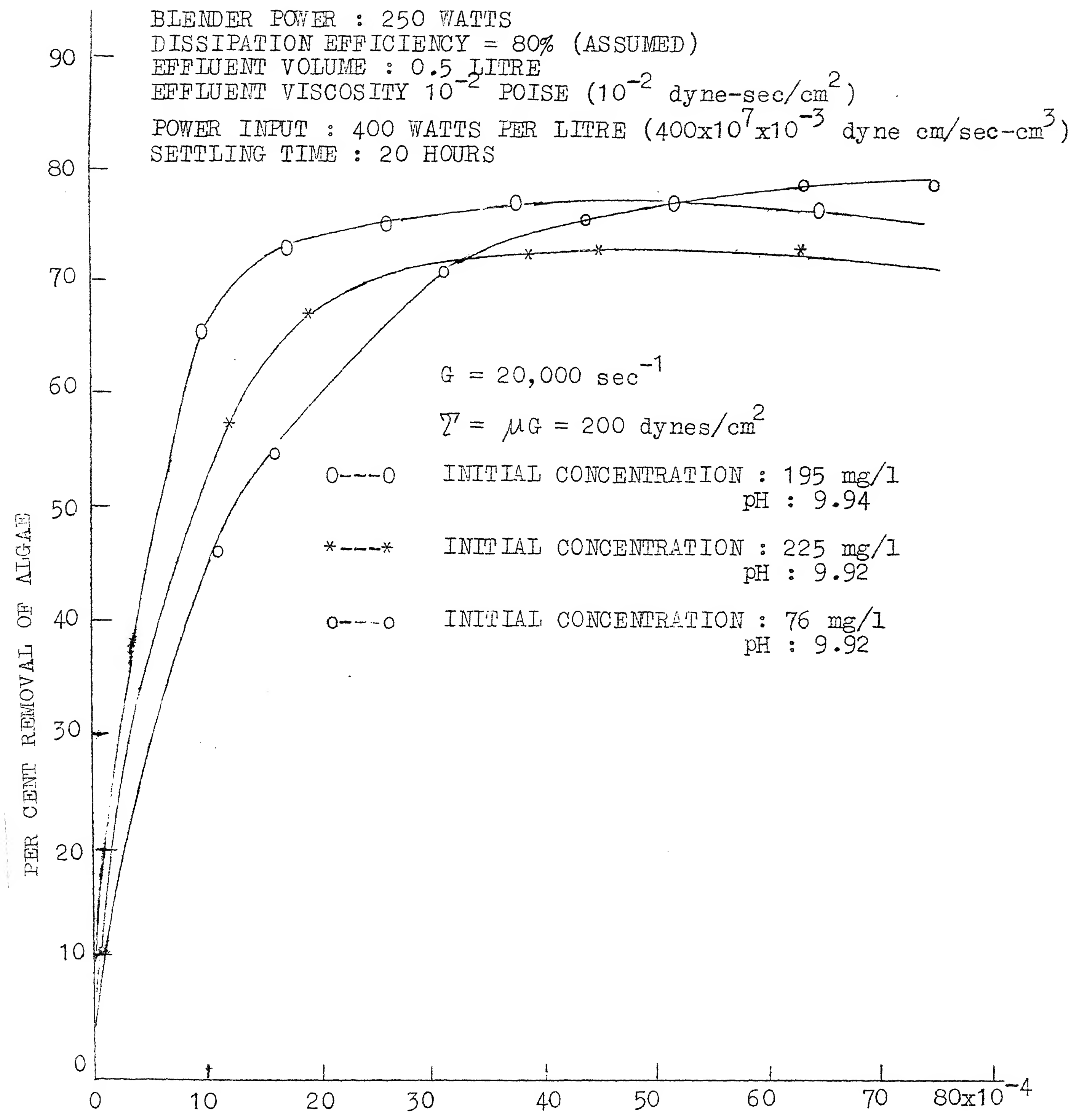


FIGURE-7 PERCENT REMOVAL VERSUS ENERGY INPUT PER LITRE BY BLENDING

The next experiment of this series was to investigate whether increasing speed had any influence on the efficiency of removal of algae. The experiment was repeated at all the three speeds at which the blender could be operated. The rates of energy consumption measured at these three speeds were 0.25, 0.33 and 0.4 KW, respectively. The experimental results are presented in Figure 8. It can be seen that the efficiency of removal increases as the blending speed i.e. the rate of energy input per unit volume is increased. A maximum removal upto the order of 90% was recorded during this experiment. This efficiency was found with the highest speed of blender.

4.6 VIABILITY OF THE HARVESTED ALGAE

4.6.1 COMPARATIVE PHOTOSYNTHETIC ACTIVITY

To study the viability of the harvested algae some qualitative and quantitative experiments were conducted. The first qualitative experiment was to compare the photosynthetic activity of the settled mass with the control. In this experiment, harvested algae and the control algae were taken in two separate test tubes. Both the samples were exposed to sunlight. The observations made were as follows :

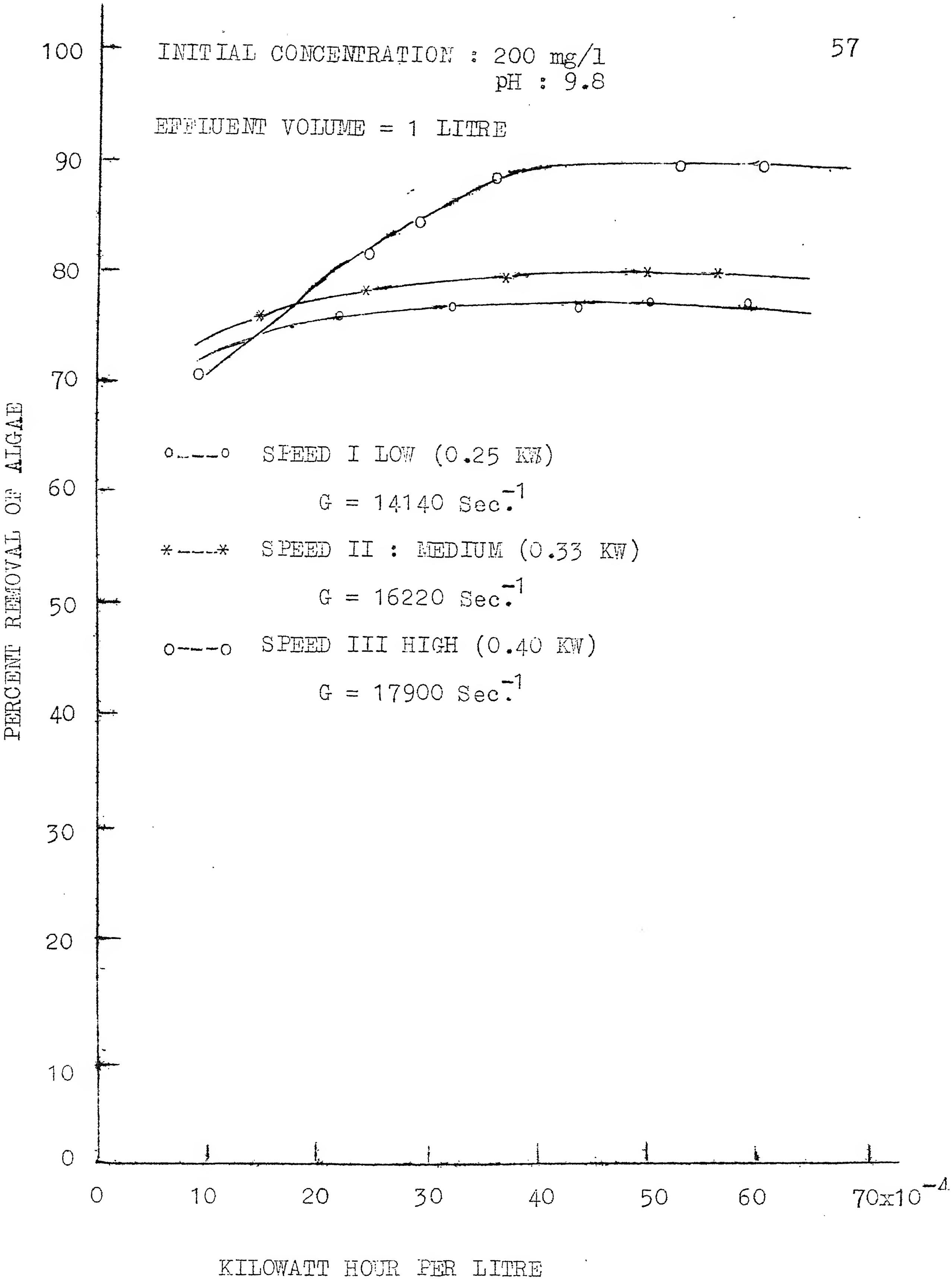


FIGURE 8 EFFECT OF BLENDING SPEED ON PERCENT REMOVAL OF ALGAE

(a) Both the samples started producing gas bubbles after about ten minutes of exposure to sunlight. Since this phenomenon could occur only in presence of light it was taken to be a photosynthetic activity. The difference observed between the two samples was that the control was able to produce gas bubbles for a much longer period (even beyond two months) while the harvested cells stopped after about a fortnight.

(b) The colour of the control remained green even beyond two to three months while that of harvested cells started changing to brownish after about a fortnight and its green colour was completely lost after about 30 to 35 days.

4.6.2 LABORATORY CULTURE OF ALGAL CELLS

Another experiment in this aspect was culturing of the control as well as the harvested algae in a synthetic media (Table 11) under a constant light of 8 Nos. of 48 in. fluorescent tubes. It was observed that the control responded positively (though growth was not prolific) while the harvested algae did not show any sign of growth even after 30 days. The inoculum in the latter case settled at the bottom of the container and the colour changed to brown.

TABLE 11

SYNTHETIC MEDIA FOR ALGAL CULTURE

INGRADIENTS	QUANTITY (gm)
$Mg\ SO_4\ 7H_2O$	0.2
$K_2H\ PO_4$	1.0
$F_e\ SO_4\ 7H_2O$	0.01
$Ca\ Cl_2$	0.02
$M_n\ Cl_2 \cdot 4H_2O$	0.002
$Na\ M_o\ O_4\ 2H_2O$	0.001
Na cl	0.5
$N\ H_4\ Cl$	1.0
Water	1000

4.6.3 POST TREATMENT EFFLUENT QUALITY

In order to check the pollutional potential of the supernatant from this process Chemical Oxygen Demand of different samples were determined as per procedure given in Standard Methods (33). The results obtained are presented in Table 12.

4.7 MECHANISM OF REMOVAL

Theoretical Considerations :

As reported by Pavoni et al. (34) bioflocculation is interpreted as resulting from the interaction of high-molecular-weight-exo-cellular polymers accumulated at the microbial surface during endogeneous growth. These polymers bond electrostatically or physically and subsequently bridge the cells of the dispersion into a three dimensional matrix of sufficient magnitude to subside under quiescent conditions. It was felt that similar phenomena may be true for algal suspensions also. In order to elucidate this two sets of experiments were conducted that are described below.

(A) A freshly collected sample of algal suspension was centrifuged at 2000, 4000, 6000, 8000 & 10,000 rpm for ten minutes in each case. The pellets formed

TABLE 12

POST-TREATMENT EFFLUENT QUALITY (COD)

SAMPLE	COD (mg/l)
Natural Pond Effluent	120
Filtered through Whatman 42	72
Blended and Filtered through Whatman 42	64
Supernatant from the Sample : treated by Blending	36

were resuspended in their respective supernatants and algae allowed to settle under quiescent conditions. Percent removals were determined spectrophotometrically at the end of 20 hours though settling as observed was rather quicker. Experimental results are presented in Figure 9. It can be seen that efficiency is maximum at centrifugation speed of about 4000 rpm, then after, it declines.

(B) It was further hypothesised that blending would effect the shearing off of the exocellular polymeric material from cell surfaces. In such case the blended suspensions (expected to contain sheared off exocellular polymers) should be able to bring down the dispersed algal cells in the natural pond effluent if mixed with it. Experiments were designed to prove this hypothesis and are described below.

One litre of algal-suspension was thoroughly blended at the highest speed as provided in the blender. The blended suspension was mixed with natural unblended suspensions in different proportions (Figure-10). The mixed suspension was kept in measuring cylinders. It was observed that algae settled down in direct proportion to the amount of blended suspension present in the

mixture of blended and unblended samples. The experimental results presented in Figure 10 indicate that blending is most probably effective, in separating exocellular polymers from cell surfaces. However, further experiments would be needed to confirm this statement.

CHAPTER V

DISCUSSION

Harvesting of algae consists of three stages.

i) Concentrating the suspensions

ii) Dewatering the sludge

iii) Drying the dewatered sludge

The present work has been limited to first stage only. The discussion of results obtained and observations made during experiments conducted for this study is presented in this chapter.

Results presented in Table - 2 show that Chlorella is the most predominant algal species amongst many others found in the stabilisation pond. Predominance of Chlorella in pond effluent renders the harvesting more desirable and profitable because of many considerations, for instance; it is highly nutritive; it contains on an average 50-60% protein, 20-30% lipids and 10 to 20% carbohydrates along with vitamins (40). Light saturation intensity for their species is 600 foot-candles only, whereas the average sunlight intensity in India is about 10,000 foot-candles (5). It is also reported (5) that Chlorella has relatively the maximum oxygen donation capacity.

From results of experiments conducted for harvesting of algae it can be said that the present work offers a good potential for harvesting of algae from stabilisation pond.

So far as mechanism of removal is concerned it appears from the experimental observations that the phenomenon of bioflocculation tends to agglomerate the algae into a biomass prior to their harvesting. This bioflocculation can be attributed to exo-cellular polymeric material from either the bacteria or the algae or both. The polymers of biological origin necessary for this bioflocculation appear to come in the reaction environment as a result of shearing when the sample from the pond-effluent is blended or recirculated through a pump. This hypothesis is indicated to be true from the results presented in Figure 10. It can be seen that the efficiency of removal is proportional to the percent of blended suspension added.

Pavoni et al. (34) have developed a sound model for mechanism of bioflocculation for bacterial suspensions. These concepts about bioflocculation proposed by Pavoni et al. appears to have superseded the concepts of previous theories such as; zoogloea ramigera theory (35), PHB (Polybeta-Hydroxy butyric Acid) theory (36) and extra-cellular polysaccharides theory (37). According to them "Bioflocculation

is viewed as the result of interaction of naturally produced, high molecular-weight-longchain polyelectrolytes with bacterial cells in such a fashion that the polyelectrolytes bridge the otherwise individual cells into an aggregate that will subside from suspension under quiescent condition". Main constituents of these polymers are (i) Polysaccharides (ii) Proteins, (iii) RNA & (iv) DNA. It has been possible to extract these natural polymers from bacterial cell - surfaces by centrifugation at high speed (32500 g) and isolate the same with ethanol technique (38). Flocculating property of these isolated polyelectrolytes has also been proved and verified by various experiments such as flocculation of the inorganic suspensions of kaolinite and Alumina as well as bacterial suspensions of various origins.

Similar phenomenon may also reasonably be expected with algal suspensions as well. Like bacteria most algal cell walls also are surrounded by flexible, gelatinous outer matrix, secreted through cell walls. It may be noted that many bacteria such as Micrococcus, Sarcina, Bacillus, Spirillum, Streptobacillus Streptococcus etc. possess morphological similarity to algal species Aphanocapsa, Merismopedia, Gleotheca, Spirullina, Phormidium and Nostoc respectively (39).

Figure 9 shows the relation between centrifugation speed, and percent algae removal. It indicates that natural polyelectrolytes are most probably sheared off during centrifugation and their quantity, quality or both are not the same at different speeds. An optimal removal is observed at 4000 rpm. It is very difficult to conclude whether this phenomenon occurs due to algal polyelectrolytes or that by bacterial polyelectrolytes or both. It appears reasonable to assume that it is due to both, since pond effluent contains both algae and bacteria. About activated sludge-suspension Bokil(44) has reported that mechanical blending positively improves the settleability of microbial suspension of activated sludge origin. He further reports that blending increases the rate of autooxidation in the absence of substrate. It breaks up the floc into individual cells and thus adsorptive sites are increased because of increased surface area. As mentioned earlier agglomeration is looked upon as an interaction of polymers of natural origins forming bridges with adjacent surfaces. This process becomes optimal in the endogenous phase, perhaps because an adequate concentration of polymer can accumulate per unit microbial surface area in this phase. It is quite possible that blending helps in bringing out this adequacy of polymer accumulation.

In qualitative experiments (para 4.6.1 and 4.6.2) it was observed that algae harvested by blending could show photosynthetic activity for comparatively lesser period than control. The former got discolored comparatively quickly and did not show any growth in synthetic media (Table 11). These observations can be explained on the logic that algal cells during blending or recirculating operation undergo some sort of physiological change on account of which they are accelerated to endogenous phase rather earlier and perhaps this is the reason of their poor photosynthetic activity, losing the natural green colour rather quicker, and inability to grow in a synthetic media.

Agglomeration and consequent settleability of algal cells are most probably due to flocculation brought about by bridging mechanism caused by natural polymers either from bacterial algal origin or from both.

The degree of removal then would depend upon the quality of polymers produced. Figure - 10 shows the relation between percent removal and percent of blended algal suspensions added to unblended one. The straight line relation indicates that the removal of algae increases with increasing amounts of blended suspensions i.e.,with

increasing quantity of separated polymers. It may be possible that in actual field operation it would not be necessary to blend the entire volume of the effluent of a pond to bring about desired percent removal of algal cells. Blending only a portion of the effluent may prove to be an economical measure.

It can be seen from Figure 6 & 7 that percent removal of algae versus energy input per unit volume of suspension is a curve of exponential nature. For a particular rate of energy input the percent removal increases as the energy input per unit volume is increased. But the curve flattens out for higher values of energy input. It indicates that there is a practical limit for maximum removal. The upper limit of percent removal in case of blending is higher (Figure - 7) than that in case of recirculating through pump (Figure - 6). This is perhaps due to higher rate of energy input with blender (400 watts per litre) than that with pump (8 watts per litre).

From Figure - 8; it can be seen that the efficiency of removal increases as the power input per unit volume of suspension increases. In other words, it can be said that the efficiency of removal increases as the Shear Gradient (G) increases. Based on the above findings it

can be concluded that high speed blender would be desirable to make the process economical. It is worth mentioning here that the geometrical shape and size of impeller are also important parameters affecting the efficiency of the process. An extensive study is required to investigate the optimal shape and size of the impeller. No such attempt has been made in the present study.

Experimental observations made for studying the viability of the algal cells harvested by this process indicate that the cells are most probably not viable as they did not show any growth whatsoever in laboratory culture medium (Table 11). Another point in favour of this statement is that the little amount of inoculum (harvested cells) which was injected into the medium settled at the bottom of the container and became discolored after about a fortnight. When it was found that the treated cells were not viable, a doubt arose whether the shearing of the cell would contribute some soluble or suspend organic compounds to the effluent. Estimation of of C.O.D. for untreated effluent, filtered effluent, sheared and settled effluent was carried out and the results are given in Table 12. Filter paper whatman No. 42 was used to remove fine suspended material including algae to have an idea of soluble C.O.D. The results indicate that

the oxidation pond effluent with the algae is having 120 mg/l of C.O.D while filtered effluent with and without shearing are almost giving 64 to 72 mg/l. The interesting result is; the sample that is treated and settled without any filtration gave about 36 mg/l of C.O.D. It appears that shearing and settling of the algae do not contribute any additional C.O.D. rather is beneficial in reducing the C.O.D.

Low-speed-mixing concept as applicable to "Activated Algae" (41) was also tried with Jar Test-Apparatus. Results have been reported in Table 9. It can be seen from the table that low-speed-mixing is not much effective in removing algae for stabilisation pond effluent.

The reason of this ineffectiveness is perhaps the low concentration of the algae in pond effluent. Mc Grief et al. (4) report that this concept was successful at high solid concentration (7000 mg/l) using activated algae.

Algae have the natural tendency to float on the surface. It was thought to utilise this property for harvesting purpose and an experiment was designed accordingly the descriptions for which has been presented in chapter 4.2.2. The experimental results are presented in Table 8. It can be seen from the table that the results are erratic. The

effluent quality after treatment does not remain consistent. The efficiency of removal as well is very low (not more than 48%). Moreover, it was impracticable to remove the algal layer from the top-of the column. It can thus be concluded that this method is not feasible in true sense for harvesting of algae.

Among all the alternatives studied blending was found to be comparatively much better and feasible.

CHAPTER VI

CONCLUSIONS

The following conclusions can be drawn from the present laboratory-scale study.

(i) Harvesting of algae is feasible by means of bioflocculation which can be induced by rapid mechanical agitation.

(ii) The process is applicable at various algal-concentrations. The efficiency of removal increases with increasing algal concentrations.

(iii) The relation between algal-removal and the energy input is exponential in nature.

(iv) Percent removal of algae increases with increasing Shear Gradient (G).

(v) The maximum algal removal is upto 90% and the cells are not viable.

(vi) The settling time for algae in this process is of the order of 20 hours.

(vii) Low-speed-mixing or agitation of stabilisation pond does not bring about appreciable removal.

(viii) Harvesting of algae by natural flotation is not practically feasible.

(ix) The effluent after treatment and settling has low C.O.D. value of the order of 36 mg/l.

CHAPTER VII

SCOPE OF FUTURE STUDIES

1. The speed of blender, its shape and size are important parameter affecting the efficiency of removal. In the present work, the study has been kept limited to a particular shape and size of blender and that also under a narrow range of speed. There is enough scope to make investigation for the optimal condition of the blending speed, the shape and size of blender etc. This can be done by studying the efficiency of removal at various speed and with various shape and size of blender.

2. So far as mechanism of removal is concerned it could not be confirmed that, like bacteria algae also contains exo-cellular polymeric materials though positive observations have been made in this favour. The work can be very well extended to isolation of exo-cellular polymeric material from algal cells and studying its flocculation property.

BIBLIOGRAPHY

1. Technical Digest, No. 10, CPHERI, Nagpur, India, October, (1970).

2. Palmer, C.M., "Algae in Water Supplies" Public Health Service Publication No. 657, Cincinnati, Ohio, (1959).

3. Kaul, S.N., "A Continuous Photosynthetic Reactor for Algae", M.Tech. Thesis, I.I.T. Kanpur (1969).

4. Oswald, W.J. & Golueke, C.G., "Water Reclamation, Algal Production and Methane Fermentation in Waste Ponds" Advances in Water Pollution Research, Vol. 2, The Mac Millan Company, N.Y. (1964).

5. Arceivala, S.J., Lakshminaryana, J.S.S., Algarsamy, S.R , and Sastry, C.A., "Waste Stabilisation Ponds - Design, Construction & Operation in India" Pub : CPHERI-Nagpur, India (1970).

6. Eckenfelder, W.W., ed:, "Advances in Water Pollution Research", Vol. 2, Mac Millan Company, N.Y. (1964).

7. Agarwal, A.L., "Some Aspects of Sewage Farming" M.Tech. Thesis, I.I.T. Kanpur (1971).

8. Saini, P.A., "Anaerobic Digestion of Algae" M.Tech. Thesis, IIT Kanpur (1971).

9. Fair, G.M., Geyer, J.C., and OKUN, D.A., "Water and Waste Water Engineering, PP. 36-29., John Wiley and Sons, Inc. (1968).

10. CPHERI, Nagpur, India "Oxidation Ponds", A brochure, (1966).

11. Golueke, C.G., Oswald, W.J. and Gee, H.K., "Harvesting and Processing of Sewage Grown Planktonic Algae". Jour. of Water Pollution Control Federation, 37, No.4 April (1965).

12. Ram Chandran, K.V., "Foam Flotation of Algae", M.Tech. Thesis, I.I.T. Kanpur (1971).

13. Kumara Sastry, A., "Algal Removal by Continuous Flotation" M.Tech. Thesis (1972).

14. Fitzgerald, G.P., and Rohlich, G.A., "An Evaluation of Stabilisation Pond Literature" Sewage and Industrial Wastes, 30, 1213 (1958).

15. Ralph Porges, "Sewage and Industrial Waste Treatment by Stabilisation Ponds" Symposium on Waste Treatment by Oxidation Ponds, CPHERI, Nagpur, India, October (1963).

16. Gillespie, C.G., "Discussion - Emergency Land Disposal of Sewage" Sewage Works, Journal, 16, 740, (1944).

17. Oswald, W.J. "Studies in Photosynthetic Oxygenation" University of California, Inst. of Engg. Research Series 44, 9, (1958).

18. Oswald, W.J., "Fundamental Factors in Stabilisation Pond Design", Proc. 3rd Conf., Biological Waste Treatment Manhattan College, New York, (1960).

19. Oswald William, J., and Gotaas, H.B., "Photosynthesis, in Sewage Treatment", Trans., Am. Soc. Civil Engrs., 122, 73, (1957).

20. Jayangoudar, I.S., "Algal Flora in Pilot Oxidation Pond at Ahmedabad", Indian Jour. of Envirin Hlth 8: 190-193 (1966).

21. Round, F.E. "Light and Temperature:Some Aspects of Their Influence on Algae". Algae, Man and the Environment, Ed., Diniel F. Jackson, Syracuse Univ. Press (1968).

22. Parhad, N.M., and Rao, N.U. "The Effect of Algal Growth on the Survival of E. coli in Sewage", Indian Jour. of Envirin Hlth, 14, (2) 131-39, April (1972).

23. Gupta, A.B. and Srivastava, G.C., "On Antibiotic Properties of Some Fresh Water Algae", Hydrobiologia, 25-26, 285, (1965).

24. Davis, E.M., and Gloyna, E.F., "Bacterial Die off in Ponds" Journal of San. Engg. Div. Proc. ASCE, SAI P:59, Feb. (1972).

25. Hodgson, H.T., "Stabilisation Ponds for Small African Urban Areas", Jour. of Water Pollution Control Federation, 36, 51 (1964).

26. Turre, George, J. "Use of Microstrainer Unit at Denver" Jour. American Water Works. Assoc., 51, 354, March (1959).

27. McGarry, M.G. and Tongkasame, C., "Water Reclamation and Algae Harvesting "Jour. Water Pollution Control Federation 43, 824-835 (1971).

28. Gloyna, E.F., Hermann, E.R. and Drynan, W.R. "Oxidation Ponds-Waste Treatment Studies, Radio Isotope Uptakes and Algae Concentration" Tech. Report No. 2, San. Engg. Lab. Univ. of Texas, Austin (1955).

29. Levin, G.V., Clendenning, J.R., Gibor, A and Boger, F.D., "Harvesting of Algae by Froth Flotation", Applied Microbiol, 10, 169, (1962).

30. Golueke, C.G., Gotaas, H.B. and Oswald, W.J., "Recovery of Algae from Waste Stabilisation Ponds, Part II" Bull. Ser. No. 8, Sanitary Engg. Research Laboratory. Univ. of Calif., Berkeley (1958).

31. Berry, E.A. "Removal of Algae by Microstrainers", Jour. Am. Water Works Assoc., 53, 1503 (1961).

32. Ives, K.J., "The Significance of Surface Electric Charge on Algae in Water Purification" Jour. Biochem and Microbial Technology & Engg. 1, 37, (1959).

33. Standard Methods for Examination of Water and Waste Water, AWWA, 13th Ed. (1971).

34. Pavoni, J.L., Tenny, M.W., and Echelberger Jr., W.F. "Bacterial Exocellular Polymers and Biological Flocculation" Jour. of Water Pollution Control Federation, Vol. 44, 414, March (1972).

35. Butterfield, C.T., "Studies of Sewage Purification II, A Zoogloea-Forming Bacterium Isolated from Activated Sludge" Public Health Report, 50, 671 (1935).

36. Crabtree, K., Boyle, W., Mc Coy, E., and Rohlich, G.A., "A Mechanism of Floc Formation by _Zoogloea remigera_" Jour. of Water Pollution Control Federation. 38, 1968 (1969).

37. Mc Kinney, R.E., "Biological Flocculation", Sewage and Industrial Waste, 24, 3, 280 (1952).

38. Ueda, S., "Production of Polysaccharide by Growing Cells "Applied Microbial. 11, 21, (1963).

39. Pelczar Jr., M.J., and Reid, R.D., "Microbiology" Mc Graw-Hill Book Company, PP:273, 2nd ed. (1965).

40. Sehgal, J.R., Field Investigation On a Waste Water Stabilisation Pond" M.Tech. Thesis, I.I.T-Kanpur (1969).

41. Sinha, A.K. "Harvesting of Algae from Oxidation Pond Effluents", M.Tech. Thesis, I.I.T. Kanpur (1969).

42. Dikshit, R. "Rahiman Poni Rakhiy Bin Pani Sab Soon" Saptahik Hindustan PP, 11, June 3 (1973).

43. Camp., T.R. and Stein, P.C. "Velocity Gradients and Internal Work in Fluid Motion", Jour. Boston Society of Civil Engrs. 30, 4,219-237 (1943).

44. Bokil, S.D. "Effect of Mechanical Blending on the Aerobic Digestion of Waste Activated Sludge" Ph.D. (Dissertation), University of Windsor, Windsor, Ontaria, Canada (1972).